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Site Evaluation for Application of Fuel Cell Technology

U.S. Coast Guard Air Station Cape Cod, MA

Michael J. Binder, Franklin H. Holcomb, William R. Taylor,
J. Michael Torrey, and John F. Westerman

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Construction Engineering
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Foreword

This study was conducted for the U.S. Coast Guard (U.S.C.G.) Air Station Cape Cod, MA under Military Interdepartmental Purchase Request (MIPR) No. W31RY-O83360270, Work Unit V69, "New TI Design of PAFC Power Plants." The technical monitor was Steve Allen, U.S. Coast Guard R&D Center.

Jim Candee, of the U.S.C.G. Research and Development Center, was the primary point of contact for the site visits, provided contact with appropriate site personnel, and collected various needed information such as energy bills, site drawings, etc. His efforts were instrumental in completing this site evaluation. In addition, David Cleveland and Bob Minervino provided important information about facility operation.

This report documents work done at the U.S. Coast Guard Air Station, Cape Cod, MA. The work was performed by the Energy Branch (CF-E), of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Michael J. Binder. Part of this work was done by Science Applications International Corporation (SAIC) under. contract No. DACA88-98-003. J. Michael Torrey and John F. Westerman are associated with SAIC. The technical editor was William J. Wolfe, Information Technology Laboratory. Larry M. Windingland is Chief, CEERD-CF-E, and L. Michael Golish is Chief, CEERD-CF. The associated Technical Director was Gary W. Schanche. The Acting Director of CERL is Dr. Alan W. Moore.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL John Morris III, EN and the Director of ERDC is Dr. James R. Houston.

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1 Introduction

Background

Fuel cells generate electricity through an electrochemical process that combines hydrogen and oxygen to generate direct current (DC) electricity. Fuel cells are an environmentally clean, quiet, and a highly efficient method for generating electricity and heat from natural gas and other fuels. Air emissions from fuel cells are so low that several Air Quality Management Districts in the United States have exempted fuel cells from requiring operating permits. Today's natural gas-fueled fuel cell power plants operate at electrical conversion efficiencies of 40 to 50 percent; these efficiencies are predicted to climb to 50 to 60 percent in the near future. In fact, if the heat from the fuel cell process is used in a cogeneration system, efficiencies can exceed 85 percent. By comparison, current conventional coal-based technologies operate at efficiencies of 33 to 35 percent.

Phosphoric Acid Fuel Cells (PAFCs) are in the initial stages of commercialization. While PAFCs are not now economically competitive with other more conventional energy production technologies, current cost projections predict that PAFC systems will become economically competitive within the next few years as market demand increases.

Fuel cell technology has been found suitable for a growing number of applications. The National Aeronautics and Space Administration (NASA) has used fuel cells for many years as the primary power source for space missions and currently uses fuel cells in the Space Shuttle program. Private corporations have recently been working on various approaches for developing fuel cells for stationary applications in the utility, industrial, and commercial markets. Researchers at the U.S. Army Engineer Research and Development Center (ERDC), Construction Engineering Research Laboratory (CERL) have actively participated in the development and application of advanced fuel cell technology since fiscal year 1993 (FY93). CERL successfully executed several research and demonstration work units with a total funding of approximately $55M.

CERL researchers have developed a methodology for selecting and evaluating application sites, have supervised the design and installation of fuel cells, and have actively monitored the operation and maintenance of fuel cells, and com-

piled "lessons learned" for feedback to manufacturers. This accumulated expertise and experience has enabled CERL to lead in the advancement of fuel cell technology through major efforts such as the DoD Fuel Cell Demonstration, the Climate Change Fuel Cell Program, research and development efforts aimed at fuel cell product improvement and cost reduction, and conferences and symposiums dedicated to the advancement of fuel cell technology and commercialization.

This report presents an overview of the information collected at the U.S. Coast Guard Air Station Cape Cod, MA, along with a conceptual fuel cell installation layout and description of potential benefits the technology can provide at that location.

Objective

The objective of this work was to evaluate the U.S. Coast Guard Air Station Cape Cod as a potential location for a fuel cell application.

Approach

On 29 and 30 October 1998, CERL and SAIC representatives visited the United States Coast Guard (U.S.C.G.) Air Station Cape Cod to investigate it as a potential location for a 200 kW fuel cell. This report presents an overview of information collected at the site along with a conceptual fuel cell installation layout and description of potential benefits. A copy of the site evaluation form filled out at the Air Station is provided as an addendum to this report.

Units of Weight and Measure

U.S. standard units of measure are used throughout this report. A table of conversion factors for Standard International (SI) units is provided below.

1 ft	=	0.305 m
1 mile	=	1.61 km
1 acre	=	0.405 ha
1 gal	=	3.78 L
°F	=	°C (X 1.8) + 32

2 Site Description

The U.S.C.G. Air Station Cape Cod (A.S.C.C.) is located within the Otis Air National Guard Base in Cape Cod, MA. A.S.C.C. is situated on 22,000 acres and is host to the Air Force Pave Paws site, Massachusetts Army National Guard, 102nd Air Force Reserve Squadron, and several other Federal agencies. A.S.C.C. consists of nearly 50 nonresidential buildings plus over 600 housing units. A.S.C.C. crews fly both HH60J "JayHawk" Helicopters and HU-25 "Falcon" Jets, which perform a variety of Coast Guard missions. Its primary mission, Search and Rescue (SAR), involves the protection of life and property in the offshore areas from the Canadian border to Long Island. In addition, A.S.C.C. plays a major role in maritime law enforcement, fisheries enforcement patrols, marine environmental protection, international ice patrols, drug interdiction, and logistics support for the many offshore lighthouses in New England.

A.S.C.C. is comprised of two main areas: the air station hangars, taxiway and related buildings (Air Station), and a larger section of the base that contains the bulk of the housing, a medical clinic, exchange, theatres, etc. (Main Base). These two areas are served by different electric utilities.

The ASHRAE design temperatures for the site are 14 and 79 °F. Extreme temperatures range from 11 to 85 °F.

Early in this study, it was determined that the focus of the A.S.C.C. fuel cell evaluation would be at the Air Station (i.e., the area adjacent to the taxiway). None of the housing, medical clinic or other buildings in the Main Base area had thermal loads large enough to utilize the fuel cell's thermal output. Therefore, the focus of the report was shifted to the Air Station.

The Bachelor Officer Quarters/Bachelor Enlisted Quarters (BOQ/BEQ) was identified as the primary candidate site at the Air Station. An office area located inside one of the hangars was evaluated, but it was determined that the thermal load was strictly a small seasonal heating load and was therefore eliminated from detailed consideration. Other buildings within the Air Station had little if any thermal load.

Site Layout

Figure 1 shows a site map of the Air Station including various buildings and the taxiway area.

Building 3159 is a BOQ/BEQ facility and also houses a galley. It was built in 1970 and was acquired by the U.S.C.G. in 1992. The 36,700 sq ft building has three floors, plus a basement and mechanical rooms. It is constructed of block and brick fascia. During the site visit, an external wall insulation material was being installed (Dryvitt or similar material) to address the building leakage issues. The building currently has the capacity for 69 people to stay overnight. There are 28 permanent party rooms (single), 9 double and 5 single student rooms, and 18 single duty personnel quarters.

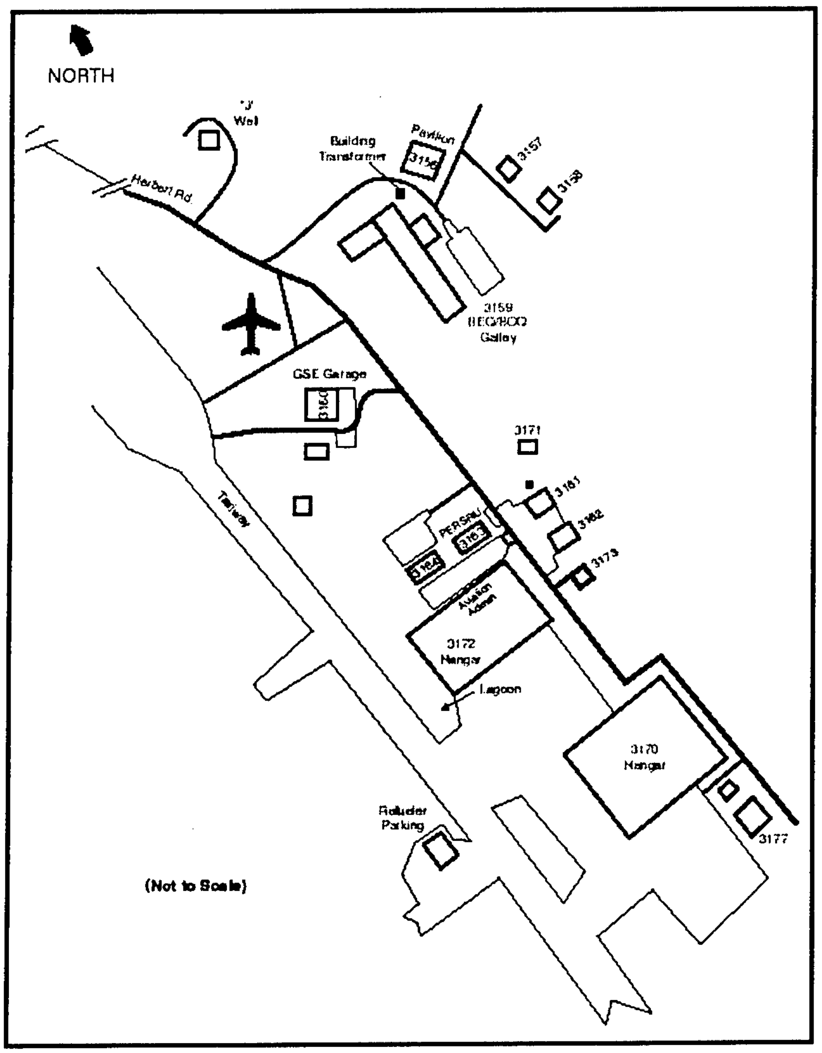

Figure 1. U.S. Coast Guard Air Station Cape Cod site map.

Electrical System

Electricity at the A.S.C.C is provided by two electric utilities. Narragansett Electric serves the Main Base and all of the Otis Air National Guard site except for the Air Station. The U.S.C.G pays Otis Air National Guard for the Main Base portion of the electric bill. The Air Station is served by COM Electric through a 1000 kVA transformer located on the south side of the Air Station.

At Building 3159, there is a 208/4160 V, 300 kVA transformer located outside near the northwest corner the building. Currently there is no 480 V power at Building 3159. To interface with the fuel cell, a new 480 V transformer would need to be installed and connected to either the 208 V side of the existing transformer or directly into the 4160 V grid.

Steam/Hot Water System

There are currently two steam boilers located in the Building 3159 mechanical room (Figure 2). One is a Kewanee 5 MMBtu/hr, and the other is a 320,000 Btu/hr Weil-McLain boiler. Steam is generated at 11 psig. The Kewanee boiler is used during the space heating season (October–April), and the smaller Weil-McLain boiler is used during the summer months. Steam is used in the building to generate domestic hot water (DHW) for the rooms and the galley as well as to heat the hydronic space heating loop. Steam also is used in the galley directly for heating cooking kettles and in the Hobart dishwashing unit. There is a 1,600 gal hot water storage tank that is currently set to a temperature of 160 °F. The 160 °F temperature is higher than normal for DHW purposes, but is specified for use in the Hobart dishwasher. (Note that the Hobart dishwasher electrically boosts the 160 °F temperature up to 180 °F.)

Space Heating System

Space heating is provided through a hydronic loop that runs throughout Building 3159. A steam-to-hot water shell and tube heat exchanger is located in the mechanical room.

Space Cooling System

Currently there is no air conditioning in Building 3159, but there are plans for a system to be installed in the near future.

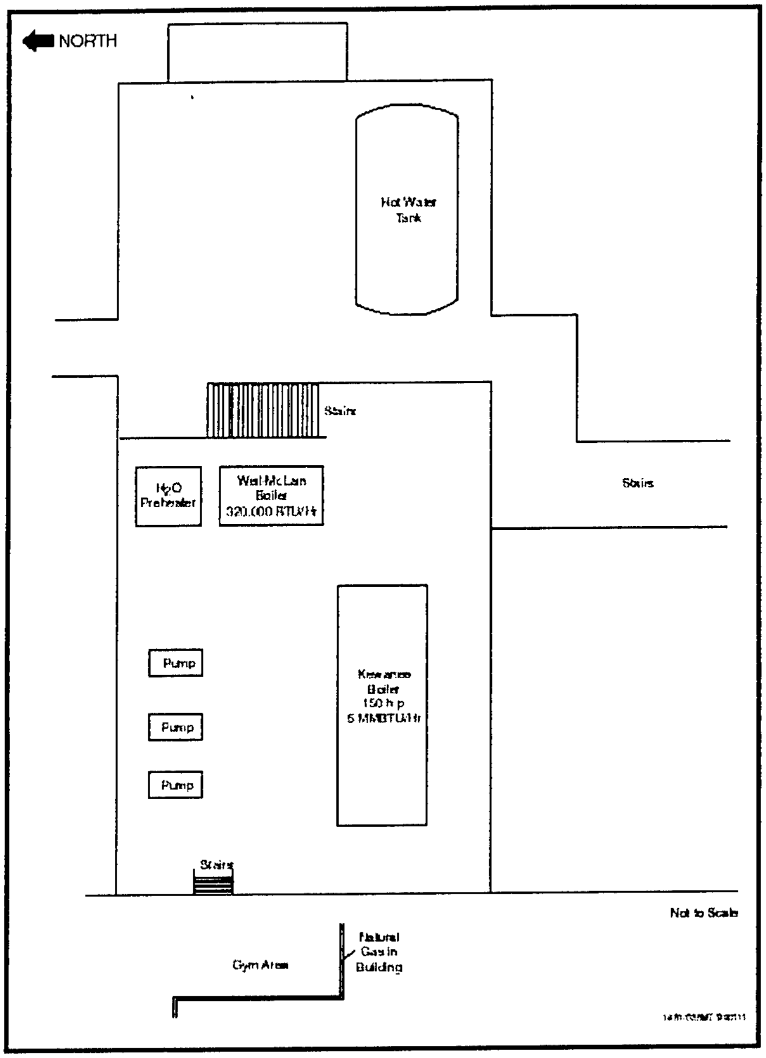

Figure 2. Building 3159 mechanical room layout.

Fuel Cell Location

The fuel cell should be sited on the south side of Building 3159 (Figure 3). The fuel cell should run east-west with the thermal outlet side facing the mechanical room. The cooling module can be located next to the fuel cell in a north-south direction. Nitrogen tanks can be placed against the mechanical room wall.

The thermal piping from the fuel cell to the mechanical room will be approximately 15 ft for the low grade loop. A high grade heat loop would be needed to interface with the space heating loop. The thermal piping run would be ~30 ft. Natural gas should be tied into the main gas line running through the building (~40 ft extension). The make-up water can be taken from inside the building (~15 ft). The electrical run will be ~100 ft to the new transformer to be located next to the existing transformer. The cooling module piping run is ~20 ft.

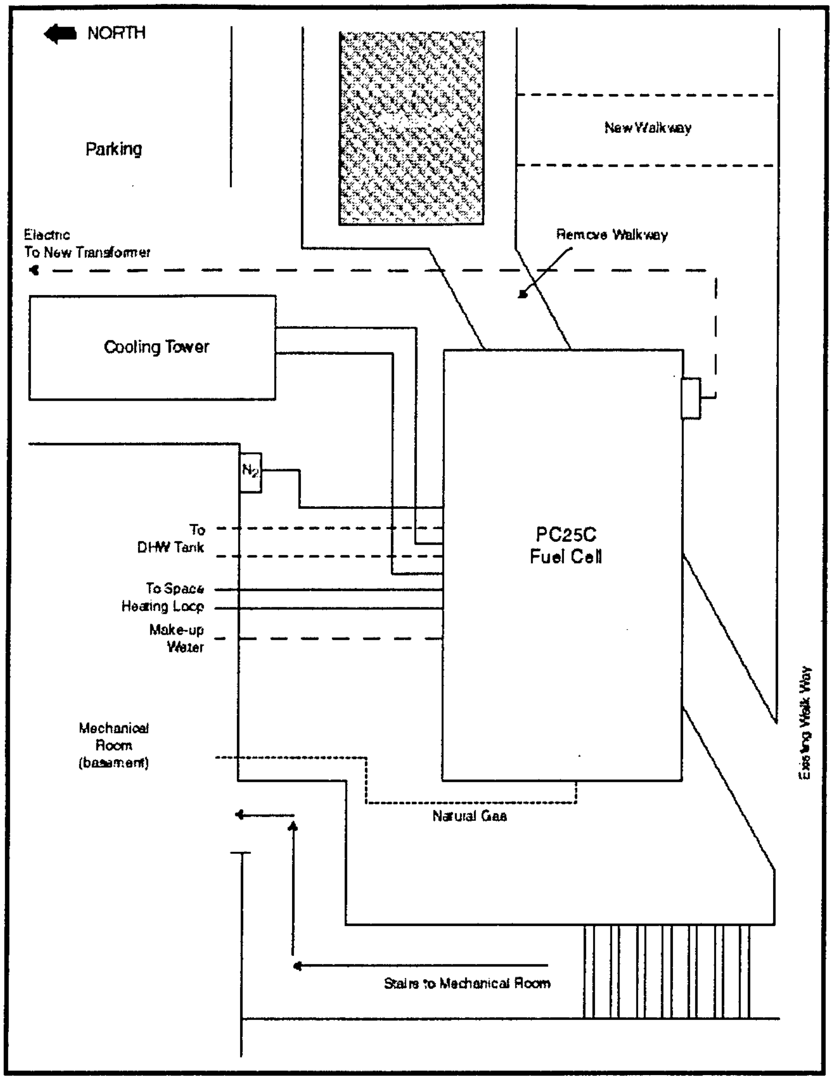

Figure 3. Fuel cell location and interfaces.

Fuel Cell Interfaces

Electrical Interface

There is a 208/4160 V, 300 kVA transformer located outside the building on the northwest corner. There are no electric loads within the building that are the same voltage as the fuel cell output of 480 V. To provide an appropriate electrical interface for the fuel cell, a new 300 kVA transformer will be required. The new transformer can be 480/4160 V and interface with the high voltage side of the existing transformer, or the new transformer can be 480/208 V and interface with the low voltage side of the transformer, which connects to the main bus bar of Building 3159. The electric load at Building 3159 is expected to drop below

the nominal 200 kW of the fuel cell at certain times. Fuel cell electric output not used at Building 3159 would be fed back to the Air Station grid.

The peak demand for the Air Station ranged from a low of 355 kW to high of 440 kW during the last year. Interval load data was provided by COM Electric for the transformer that serves the entire Air Station load (Table 1). These data indicate that the Air Station total load falls below the fuel cell's 200 kW output only 0.2 percent of the time. Output loads between 201–250 kW occur only 1.6 percent of the time.

A special meter should be installed so that, when the total load of the Air Station drops to approximately 230 kW, the fuel cell would incrementally drop its load output by a set amount. This will ensure that the fuel cell never exports electricity to the COM Electric utility grid.

Thermal Interface

The two major thermal loads within Building 3159: are: (1) Domestic Hot Water (DHW), and (2) space heating. Heat is generated for both of these loads by two steam boilers. One boiler has a capacity of 5 MMBtu/hr and is used primarily during the winter months. The second boiler has a capacity of 320,000 Btu/hr and is used as the primary heating source in the summer. Both of the thermal loads are analyzed below to determine their viability for utilizing fuel cell heat.

Domestic Hot Water Heating Requirements

The DHW system consists of a 1600-gal storage tank, which is heated by either of the two steam boilers. The hot water is used for showers, hand sinks, laundry, and a kitchen. The set point temperature for the storage tank currently is 160 °F to accommodate temperature requirements for kitchen equipment.

Table 1. Air station electric load data.

	Hours by kW Demand Group			
	0–200	201–250	> 250	All
01May97–31Jul97	25.3	29.0	2,153.8	2,208
01Aug97–30Sep97	—	28.5	1,435.5	1,464
01Oct97–31Dec97	3.0	36.5	2,168.5	2,208
01Jan98–31Mar98	—	28.8	2,131.3	2,160
01Apr98 – 30Jun98	—	62.5	2,121.5	2,184
01Jul98 – 31Aug98	—	—	1,488.0	1,488
Total Hours	28	185	11,499	11,712
Percent of Total Hours	0.2%	1.6%	98.2%	100.0%

There are two circulating loops from the storage tank. One loop is 160 °F and supplies the kitchen, and the other loop is 140 °F and supplies hot water for the other DHW loads. Figure 4 shows the existing DHW system configuration.

For the purposes of this analysis, the DHW loads are separated into the non-kitchen loads and the kitchen loads. To estimate the contribution of the fuel cell for supplemental heating of the DHW system, the following inputs and assumptions are used:

- The facility is occupied 24 hours per day, 365 days per year.
- The makeup of the occupants using the facility is 75 percent male and 25 percent female.
- 95 percent of the occupants use the facility each day.
- The average temperature of the cold water makeup is 60 °F.
- The DHW temperature set point is 160 °F.
- Non-kitchen DHW loads use 140 °F water.

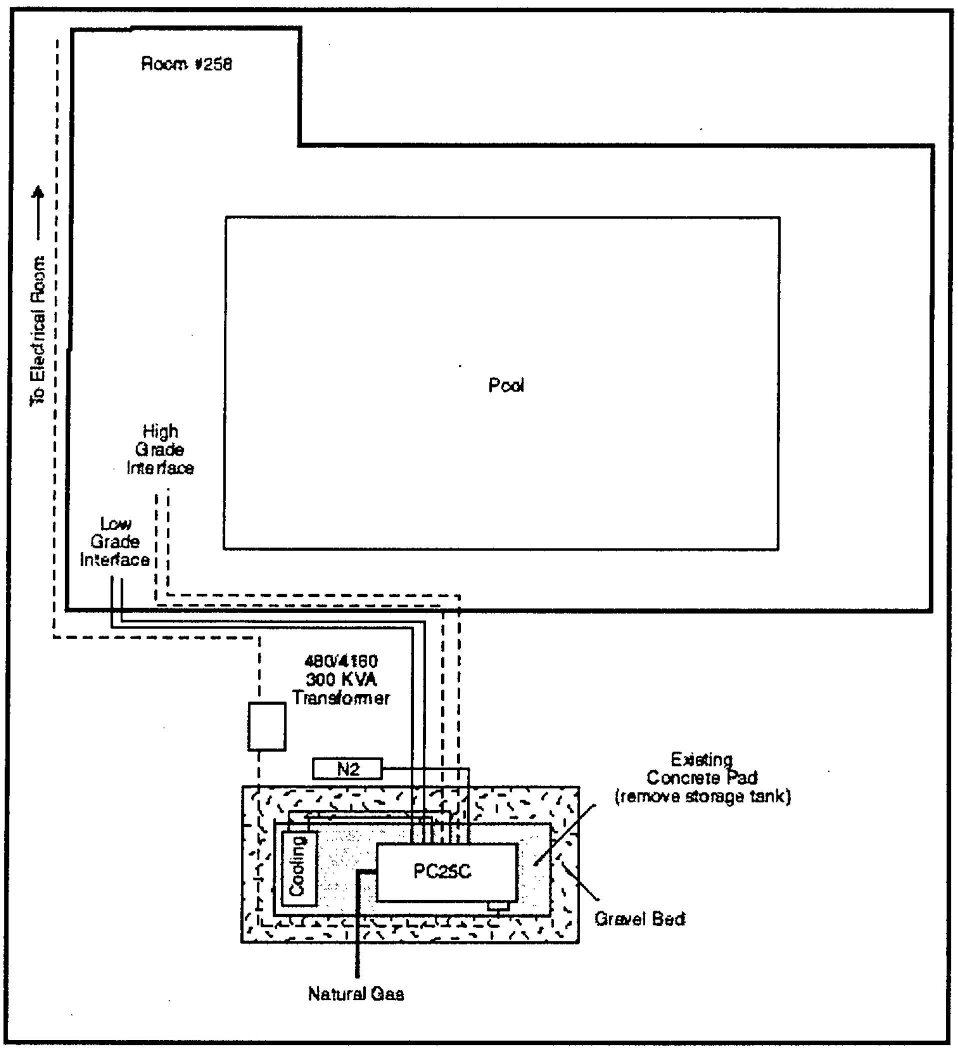

Figure 4. Roland Hall fuel cell location and interfaces.

Using hot water demand reference data from the 1991 ASHRAE Applications Handbook (Chapter 44, "Service Water Heating"), the closest description to Building 3159 is a dormitory that consists of showers, lavatories, service sinks, and washing machines. On average, hot water demand is estimated to be 13.1 gal/occupant/day for men and 12.3 gal/occupant/day for women. Assuming that the mix of occupants is 75 percent male and 25 percent female, an average daily rate of hot water consumption of 12.9 gal/occupant/day was used.

**12.9 gal/occupant/day = [(75% x 13.1 gal/occupant/day) +
(25% x 12.3 gal/occupant/day)]/100%**

Assuming an occupancy load factor of 95 percent, the average heating rate required to heat the makeup water (12.9 gal/occupant/day) and maintain the storage temperature at 160 °F at all times is 29,349 Btu/hr.

**29,349 Btu/hr =66 occupants/day x 12.9 gal/occ/day x 8.33 lb/gal x
1 Btu/lb °F x (160–60) °F 24 hours/day**

In addition to the makeup water heating requirement, heating is required to compensate for losses due to the DHW recirculation loop. The recirculation losses are estimated as follows:

- Flow Rate: 20 gpm
- Supply Temperature: 140 °F
- Return Temperature (winter): 125 °F
- Return Temperature (summer): 135 °F.

The resulting loss in the winter is 149,940 Btu/hr:

20 gal/min x 8.33 lb/gal x 1.0 Btu/lb °F x (140 – 125) °F x 60 min/hr

The resulting loss in the summer is 49,980 Btu/hr:

20 gal/min x 8.33 lb/gal x 1.0 Btu/lb °F x (140 – 135) °F x 60 min/hr

Note that the only difference between the winter and summer recirculation losses is the estimated return temperature.

To estimate the annual demand for the non-kitchen DHW, the above rate of heating is assumed to be constant throughout the year. That is to say, usage of the facility is fairly constant from one month to the next. Table 2 lists the monthly consumption.

Table 2. Building 3159 non-kitchen DHW load.

Month	Operation: Days/Month	Recirculation Losses (kBtu/hr)	Recirculation Losses (kBtu/mo)	Makeup Water (kBtu/mo)	kBtu/mo
January	31	149.9	111,555.4	21,835.8	133,391.2
February	28	149.9	100,759.7	19,722.7	120,482.3
March	31	149.9	111,555.4	21,835.8	133,391.2
April	30	149.9	107,956.8	21,131.4	129,088.2
May	31	50.0	37,185.1	21,835.8	59,020.9
June	30	50.0	35,985.6	21,131.4	57,117.0
July	31	50.0	37,185.1	21,835.8	59,020.9
August	31	50.0	37,185.1	21,835.8	59,020.9
September	30	50.0	35,985.6	21,131.4	57,117.0
October	31	149.9	111,555.4	21,835.8	133,391.2
November	30	149.9	107,956.8	21,131.4	129,088.2
December	31	149.9	111,555.4	21,835.8	133,391.2
Total	365		946,421.3	257,098.9	1,203,520.2

The total available thermal output from the fuel cell during the year is 6,132,000 kBtu (700 kBtu/hr x 24 Hours/Day x 365 Days/Year). Therefore, the DHW load represents a thermal utilization of 19.6 percent (1,203,520 / 6,132,000).

To estimate the hot water demand for the kitchen, reference data was utilized from the 1991 ASHRAE Applications Handbook (Chapter 44, "Service Water Heating"). Data is presented for two categories of service as follows:

1. Full meal restaurants and cafeterias: 2.4 gal/meal
2. Grills, sandwich shops and snack shops: 0.7 gal/meal.

Data provided on kitchen usage indicates that two types of meals are typically prepared: meals in the galley and flight meals (e.g., box lunches). For purposes of this analysis, meals in the galley were assumed to use 2.4 gal/meal and flight meals were assumed to use 0.7 gal per meal. Using meal data provided by A.S.C.C, water usage was calculated using the above assumptions for two months as presented in Table 3.

These data are used to develop an annual demand profile for the kitchen DHW load. Note that the data for the 2 months presented above were provided by the Air Station and that the individual monthly load factors shown below were changed to establish a transition from July to November and November to July. To estimate the average hourly rate of heating required, it was assumed that the kitchen operates an average of 12 hours per day. The annual demand is presented in Table 4.

Table 3. Kitchen hot water usage estimates.

	Meal Type	Number of Meals	gal/meal	gal/month	gal/day
Jul	Galley	5,077.0	2.4	12,184.8	393.1
	Flight	1,512.0	0.7	1,058.4	34.1
	Total	6,589.0		13,243.2	427.2
Nov	Galley	2,997.0	2.4	7,192.8	232.0
	Flight	1,296.0	0.7	907.2	29.3
	Total	4,293.0		8,100.0	261.3

Table 4. Building 3159 kitchen DHW load.

Month	Operation (days/mo)	Operation (hr/mo)	Occupant Load Factor	Meals/day	gal/day	kBtu/hr	kBtu/mo
January	31	372	61%	109	261.3	21.8	8,095.7
February	28	336	61%	109	261.3	21.8	7,312.3
March	31	372	70%	125	299.1	24.9	9,267.4
April	30	360	95%	169	405.9	33.8	12,171.4
May	31	372	100%	178	427.2	35.6	13,239.1
June	30	360	100%	178	427.2	35.6	12,812.0
July	31	372	100%	178	427.2	35.6	13,239.1
August	31	372	95%	169	405.9	33.8	12,577.2
September	30	360	90%	160	384.5	32.0	11,530.8
October	31	372	82%	146	350.3	29.2	10,856.1
November	30	360	61%	109	261.3	21.8	7,834.6
December	31	372	61%	109	261.3	21.8	8,095.7
Total	365	4,380					127,031.4

In addition to the makeup water heating requirement, heating is required to compensate for losses due to the kitchen DHW recirculation loop. The recirculation losses are estimated as follows:

- Flow Rate: 20 gpm
- Supply Temperature: 160 °F
- Return Temperature (winter): 150 °F
- Return Temperature (summer): 155 °F.

The resulting loss in the winter is 99,960 Btu/hr:

20 gal/min x 8.33 lb/gal x 1.0 Btu/lb °F x (160 – 150) °F x 60 min/hr

The resulting loss in the summer is 49,980 Btu/hr:

20 gal/min x 8.33 lb/gal x 1.0 Btu/lb °F x (160 – 155) °F x 60 min/hr

Table 5. Recirculation losses for Building 3159 kitchen DHW load.

Month	Operation (days/mo)	Recirculation Losses (Btu/hr	Recirculation Losses (Btu/mo)	Makeup Water (Btu/mo)	kBtu/mo
January	31	100.0	74,370.2	8,095.7	82,466.0
February	28	100.0	67,173.1	7,312.3	74,485.4
March	31	100.0	74,370.2	9,267.4	83,637.6
April	30	100.0	71,971.2	12,171.4	84,142.6
May	31	50.0	37,185.1	13,239.1	50,424.2
June	30	50.0	35,985.6	12,812.0	48,797.6
July	31	50.0	37,185.1	13,239.1	50,424.2
August	31	50.0	37,185.1	12,577.2	49,762.3
September	30	50.0	35,985.6	11,530.8	47,516.4
October	31	100.0	74,370.2	10,856.1	85,226.3
November	30	100.0	71,971.2	7,834.6	79,805.8
December	31	100.0	74,370.2	8,095.7	82,466.0
Total	365		692,123.0	127,031.4	819,154.5

Note again that the only difference between the winter and summer recirculation losses is the estimated return temperature.

To estimate the annual demand for the kitchen DHW, the above rate of makeup water and recirculation losses were combined. The monthly consumption is presented in Table 5. The fuel cell thermal use for the kitchen DHW totals 13.4 percent (819,154 / 6,132,000).

To verify that the estimates for the DHW presented above are reasonable, the summer gas requirements were compared to the historical summer gas bills. Summer months were analyzed since there would not be any gas consumption for space heating during this time period. July billing data indicates that 174,500 cu ft were consumed. DHW estimates for July make-up and recirculation requirements are 109,441 kBtu (59,020.9 + 50,424.2). Assuming a boiler efficiency of 75 percent, the natural gas requirement to meet this load is 150,229 cu ft.

150,229 cu ft = 109,441 kBtu/Month x (1 cu ft/1.00 kBtu) x (1/ 0.75)

This leaves 24,271 cu ft (174,500 – 150,229) of natural gas for kitchen equipment requirements. Therefore the estimates are within the historical consumption rates for natural gas and are reasonable.

Since the return temperature from the kitchen is estimated to be approximately 145 to 155 °F, the high grade heat exchanger option would be required to ac-

commodate this load. The maximum capacity of the high grade heat exchanger is 350,000 Btu/hr. To take advantage of the maximum benefit of the fuel cell thermal output, a control strategy needs to be incorporated that will give priority to the fuel cell for heating the storage tank. The storage tank set point temperature should remain at 160 °F, but the steam loop control to begin heating should be lowered. Thus, as long as the fuel cell can keep up with the heating requirement, the steam will not come on. In the case where the DHW demand significantly exceeds the fuel cell capacity (i.e., the storage tank temperature falls below 150 °F), the steam will come on and heat the tank to 160 °F.

The thermal interface for the DHW tank (160 °F) is presented in Figure 5. The non-kitchen recirculation loop is serviced by the fuel cell low grade heat exchanger, and the kitchen recirculation loop is serviced by the fuel cell high grade heat exchanger.

Another option for integrating the fuel cell to the DHW storage tank is to lower the tank temperature from 160 to 140 °F. Discussions with the kitchen personnel revealed that the only reason for the 160 °F water was for the Hobart dishwasher. The Hobart has an internal heater that further boosts this temperature to 180 °F. By lowering the storage tank temperature, energy savings can be achieved through reduced recirculation losses and by lowering the temperature differential between the incoming makeup water and the storage tank set point.

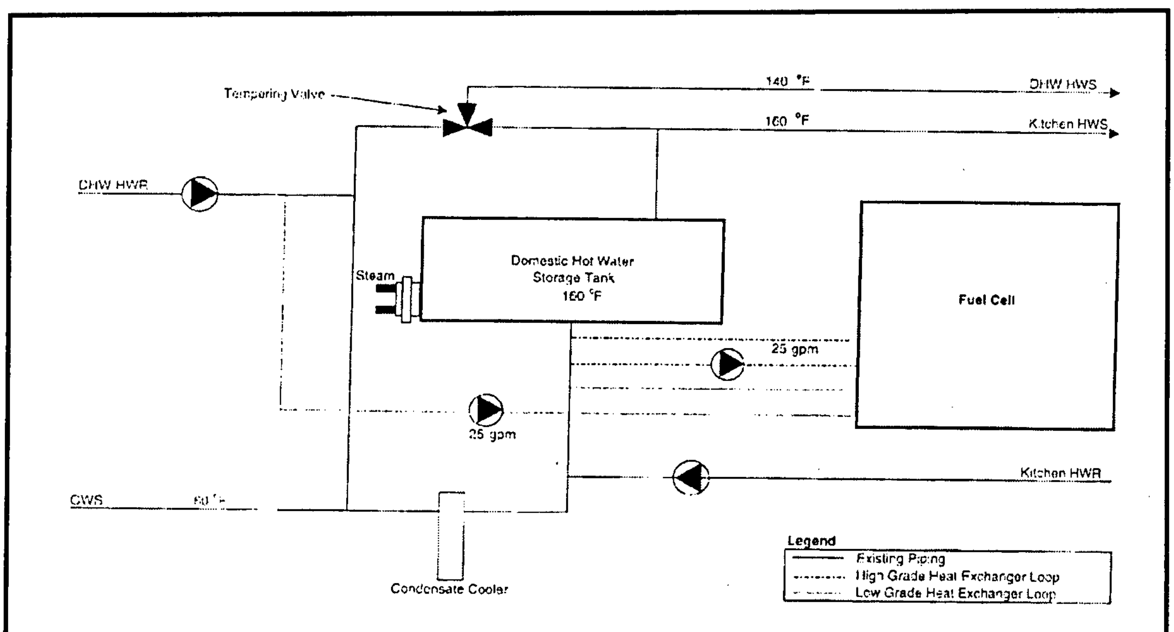

Figure 5. Building 3159 fuel cell DHW interface with 160 °F storage temperature.

This also has an impact on the fuel cell integration in that it would eliminate the requirement for a high grade heat exchanger for the DHW high temperature load. This option is explored below based on the following assumptions:

- Storage Set Point Temperature: 140 °F
- Kitchen Load:
  - Flow Rate: 20 gpm
  - Supply Temperature: 140 °F
  - Return Temperature (winter): 130 °F
  - Return Temperature (summer): 135 °F
- Non-kitchen:
  - Flow Rate: 20 gpm
  - Supply Temperature: 140 °F
  - Return Temperature (winter): 125 °F
  - Return Temperature (summer): 130 °F

Tables 6 and 7 list the resulting hot water loads.

The resulting annual thermal recovery for interfacing the fuel cell with the 140 °F storage tank is 1,928,911 kBtu (1,152,100 + 776,811). This represents a thermal utilization of 31.5 percent (1,928,911 / 6,132,000). The fuel cell interface is presented in Figure 6 for the case in which no high grade heat exchanger is required.

Table 6. Building 3159 non-kitchen DHW load.

Month	Operation Days/mo	Recirculation Losses (kBtu/hr)	Recirculation Losses kBtu/mo	Makeup Water (kBtu/mo)	kBtu/mo
January	31	149.9	111,555.4	17,468.6	129,024.0
February	28	149.9	100,759.7	15,778.1	116,537.8
March	31	149.9	111,555.4	17,468.6	129,024.0
April	30	149.9	107,956.8	16,905.1	124,861.9
May	31	50.0	37,185.1	17,468.6	54,653.8
June	30	50.0	35,985.6	16,905.1	52,890.7
July	31	50.0	37,185.1	17,468.6	54,653.8
August	31	50.0	37,185.1	17,468.6	54,653.8
September	30	50.0	35,985.6	16,905.1	52,890.7
October	31	149.9	111,555.4	17,468.6	129,024.0
November	30	149.9	107,956.8	16,905.1	124,861.9
December	31	149.9	111,555.4	17,468.6	129,024.0
Total	365		946,421.3	205,679.1	1,152,100.4

Table 7. Recirculation losses for Building 3159 non-kitchen DHW load.

Month	Operation (days/mo)	Recirculation Losses (kBtu/hr)	Recirculation Losses (kBtu/mo)	Makeup Water (kBtu/mo)	kBtu/mo
January	31	100.0	74,370.2	5,397.1	79,767.4
February	28	100.0	67,173.1	4,874.8	72,048.0
March	31	100.0	74,370.2	6,178.3	80,548.5
April	30	100.0	71,971.2	8,114.3	80,085.5
May	31	50.0	37,185.1	8,826.1	46,011.2
June	30	50.0	35,985.6	8,541.4	44,527.0
July	31	50.0	37,185.1	8,826.1	46,011.2
August	31	50.0	37,185.1	8,384.8	45,569.9
September	30	50.0	35,985.6	7,687.2	43,672.8
October	31	100.0	74,370.2	7,237.4	81,607.6
November	30	100.0	71,971.2	5,223.0	77,194.2
December	31	100.0	74,370.2	5,397.1	79,767.4
Total	365		692,123.0	84,687.6	776,810.6

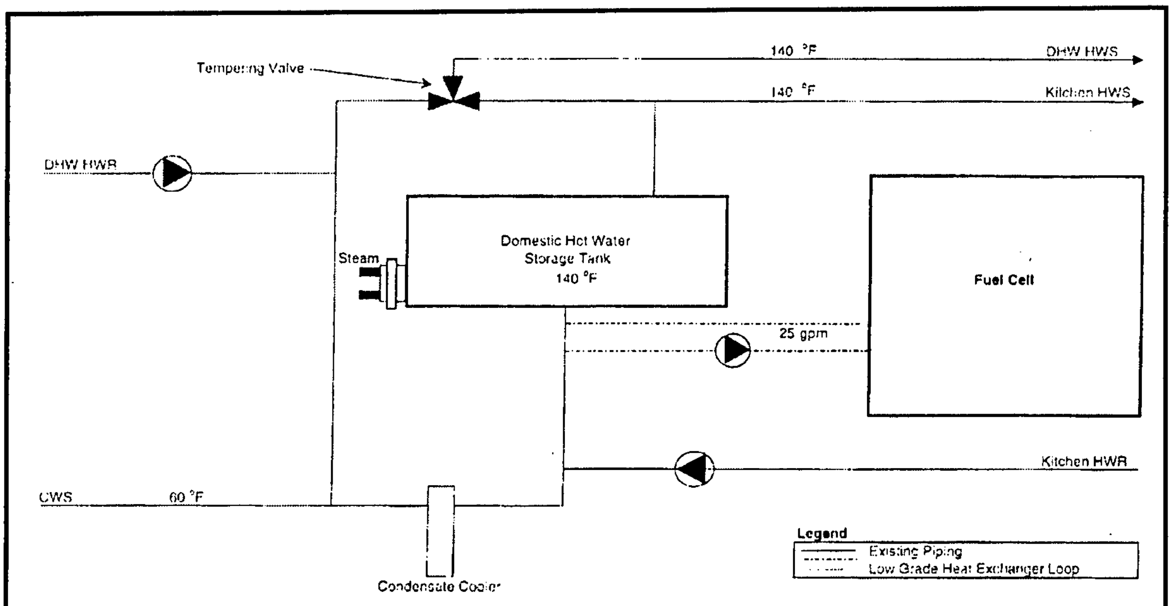

Figure 6. Building 3159 fuel cell DHW interface with 140 °F storage temperature.

Space Heating Requirements

Providing space heating to the building using heat recovered from the fuel cell also was evaluated. The temperature set point for the heating hydronic loop is variable. The set point control scheme is to provide 180 °F water when the outdoor dry bulb temperature is 0 °F. The set point is then lowered ~5 °F for each 1 °F increase in the outdoor temperature. To accommodate the times when the

high temperature water is required, the fuel cell would need to be purchased with the high grade heat exchanger option. To estimate the heating load of the building, the U-value for the various building envelope components were estimated from previous base energy studies. Table 8 lists the design day heating load for Building 3159.

Historical temperature bin data was used to estimate the annual potential fuel cell heat recovery for space heating. The bin data was obtained from a software package developed by the Gas Research Institute (GRI) called "BinMaker™: The Weather Summary Tool." BinMaker™ data is based on TMY-2 data gathered by the National Renewable Energy Laboratory in Golden, CO. Table 9 lists the monthly hours of heating required for the building, based on outdoor dry bulb temperature.

To estimate the average building heating load during each month, the average outdoor temperature was substituted for the winter design temperature input in Table 8 to get the heating load calculation result. Since the resulting average building heating load is greater than the high grade heat exchanger capacity, it is assumed that the full capacity of the high grade heat will be utilized during the hours of heating demand. Table 10 lists the estimated monthly space heating requirement. The space heating load represents a fuel cell thermal utilization of 20.9 percent (1,283,450 / 6,132,000).

Table 8. Building 3159 space heating load calculations.

***Design* Conditions**					
Floor area	36700 sq ft				
Winter design temperature	14 Dry Bulb				
Indoor design temperature	70 Dry Bulb				
Transmission					
Description	*Area*	*U-Value*	*Factor*	*Delta-T*	*Btu/Hr*
Glazing: dual	4446.0	0.57	1	56	141,916
Wall	13087.0	0.27	1.18	56	233,493
Ceiling	6460.0	0.05	1.18	56	21,344
Floor: slab perimeter	416.0	0.9	1	28	10,483
Sub-Total					407,236
Infiltration					
Description	*Area*	*Height*	*Factor*	*Delta-T*	*Btu/hr*
	36700	8.5	0.018	56	314,446
Duct Losses					
Percent of load		10%			72,168
Total hourly heat loss (Btu/Hr)					793,850

Table 9. Weather bin data for Cape Cod.

Month	Hours	Avg. Temp. (°F)
January	723	28.9
February	661	31.0
March	642	34.4
April	422	40.7
May	31	42.5
June	0	—
July	0	—
August	0	—
September	0	—
October	102	43.5
November	469	37.3
December	617	30.9

Table 10. Building 3159 space heating load estimates.

Month	Hours of Heating	Average Building Load (kBtu/hr)	Average Fuel Cell Contribution (kBtu/hr)	Monthly Heat Recovered (kBtu)
January	723	582.6	350	253,050
February	661	552.9	350	231,350
March	642	504.7	350	224,700
April	422	415.4	350	147,700
May	31	389.8	350	10,850
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	102	375.7	350	35,700
November	469	463.6	350	164,150
December	617	554.3	350	215,950
Total	3,667.0			1,283,450

The ONSI literature indicates that the high grade heat exchanger is capable of providing 350,000 Btu/hr with an inlet temperature of 160 °F. The fuel cell interface would be made on the return water piping of the hot water loop. Figure 7 shows the fuel cell interface to preheat the hot water return for space heating. A 25 gpm pump would pull 160 °F water from the loop and pass it through the fuel cell. The fuel cell with a maximum high temperature heating capacity of 350,000 Btu/hr would then heat the water to 188 °F. The 188 °F water would then be introduced back into the return water loop where the mixed temperature entering the steam to hot water heat exchanger would be 171.7 °F.

171.7 °F = ((25 gpm x 160 °F) + (5 gpm x 188 °F)) / 60 gpm188 °F = 160 °F +
350,000 Btu/hr (25 gal/min x 8.33 lb/gal x 1.0 Btu/lb °F x 60 min/hr)

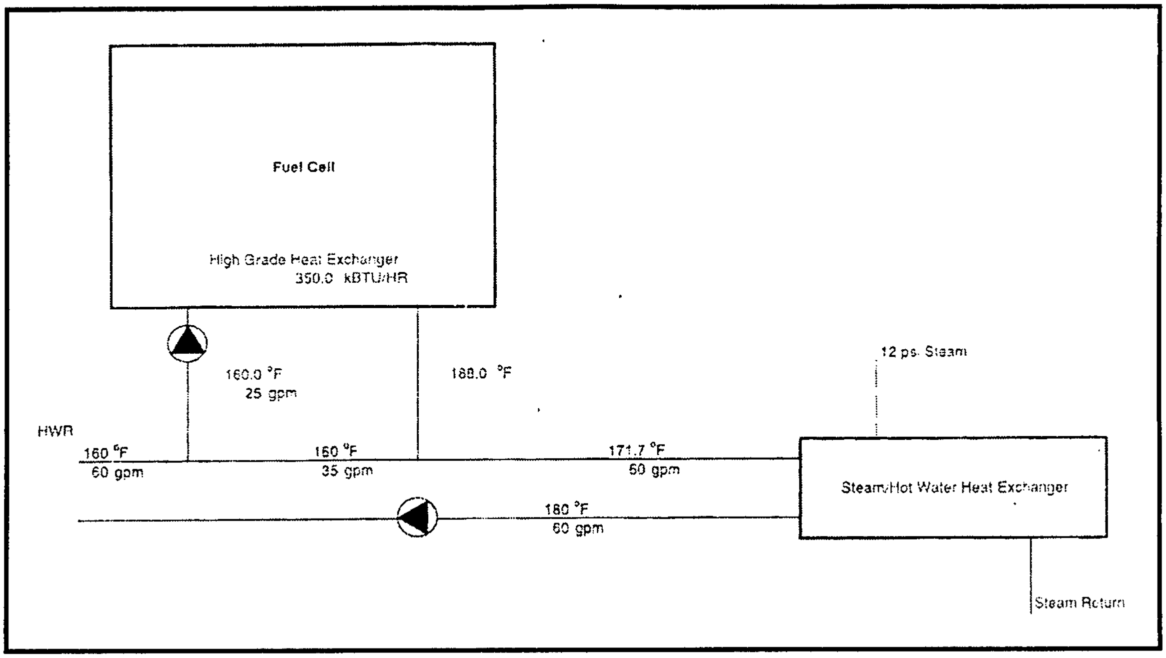

Figure 7. Building 3159 space heating loop heating recovery.

As previously noted, interfacing with the kitchen DHW while maintaining a storage tank temperature at 160 °F and the space heating loads will require the high grade heat exchanger option on the fuel cell. If both of these loads are interfaced to the fuel cell, there are two implications:

1. The total kitchen demand and the space heating demand as previously estimated are not additive because the combined loads will exceed 350,000 kBtu/hr at certain times. Table 11 lists the estimated fuel cell heating contributions if all three heating loads are integrated to the fuel cell. This estimate assumes that the space heating load is satisfied first. The kitchen load is estimated by subtracting space heating hours in the month from the month hours and multiplying by the average kitchen Btu/hr. This is only a method of estimating the load and is not a model of operation. The resulting thermal utilization is 45.9 percent (2,814,089 / 6,132,000).
2. An intermediate heat exchanger will be required to prevent mixing potable water with the space heating water. The intermediate heat exchanger will impact supply temperatures and require an additional pump.

Note that, under fuel cell operation, the thermal loads associated with the high grade heat exchanger have a higher priority than the loads from the low grade heat recovery heat exchanger since the two heat exchangers are piped in series within the fuel cell.

Table 11. Space heating load for combined interface loads.

Month	Non-Kitchen DHW (kBtu)	Kitchen DHW (kBtu)	Space Heating (kBtu)	Total
January	133,391.2	2,099.2	253,050.0	388,540.3
February	120,482.3	1,099.6	231,350.0	352,931.9
March	133,391.2	10,195.9	224,700.0	368,287.1
April	129,088.2	29,788.1	147,700.0	306,576.3
May	59,020.9	35,635.7	10,850.0	105,506.7
June	57,117.0	35,985.6	0.0	93,102.6
July	59,020.9	37,185.1	0.0	96,206.0
August	59,020.9	37,185.1	0.0	96,206.0
September	57,117.0	35,985.6	0.0	93,102.6
October	133,391.2	64,174.3	35,700.0	233,265.5
November	129,088.2	25,090.0	164,150.0	318,328.2
December	133,391.2	12,694.9	215,950.0	362,036.1
Total	1,203,520.2	327,119.1	1,283,450.0	2,814,089.3

Alternatively, lowering the storage tank temperature to 140 °F will eliminate the need for the high grade heat exchanger for the DHW storage tank. Thus, the combined DHW and space heating loads will result in a thermal utilization of 52.4 percent (31.5 + 20.9).

Summary of Thermal Interface Options

Maintaining the DHW storage tank temperature at 160 °F and supplying heat to the recirculation loops requires that a high grade heat exchanger be purchased with the fuel cell. If the DHW storage tank temperature is lowered to 140 °F, then a high grade heat exchanger will not be required for the DHW loads. A high grade heat exchanger will be required for interfacing with the space heating loop. Table 12 lists a summary of the options discussed along with their respective displaced thermal energy and fuel cell thermal utilization.

Natural Gas Interface

Building 3159 has an existing 4-in. natural gas pipeline up to the west wall of the mechanical room. The pressure of the gas line is 8-in. wc. The natural gas supply for the fuel cell would be a 2-in. pipe tapped off the 4-in. line and run to the location of the fuel cell through the mechanical room. If the pressure is not enough for the fuel cell, then a new gas line will have to be brought in from the north side of the building.

Table 12. Summary of thermal energy savings scenarios.

Thermal Load Application (DHW Tank Temp. Set Point)	Fuel Cell Heat Exchanger	Displaced Thermal (kBtu/yr)	Thermal Utilization (%)
Kitchen DHW only (160 °F)	High Grade	819,154	13.4
Non-kitchen DHW only (160 °F)	Low Grade	1,203,520	19.6
Both Kitchen/Non-kitchen (160 °F)	High/Low	2,022,674	33.0
Both Kitchen/Non-kitchen (140 °F)	Low Grade	1,928,911	31.5
Space Heating Only (n/a)	High Grade	1,283,450	20.9
DHW/Space Heat (160°F)	High/Low	2,814,089	45.9
DHW/Space Heat (140°F)	High/Low	3,212,361	52.4

3 Economic Analysis

Electricity is provided to the A.S.C.C by two electric utilities: Narragansett Electric for the Main Base and COM Electric for the Air Station. The A.S.C.C pays the Otis Air National Guard Base directly under a sub-metering arrangement for electricity delivered by Narragansett. COM Electric provides electricity to the Air Station under rate schedule Medium General Time-of-Use (TOU)–Rate G-2. This time-of-use rate schedule is divided into three periods as shown in Table 13.

Table 13. Air Station Time-of-Use (TOU)—Rate G-2 Schedule.

Period	Daylight Savings Time	Eastern Standard Time
Peak (Mon.-Fri.)	9 a.m. – 6 p.m.	4 p.m.– 9 p.m.
Low A (Mon.-Fri.)	7 a.m. – 9 a.m. + 6 p.m.-10 p.m.	7 a.m. – 4 p.m. + 9 p.m.–10 p.m.
Low B	Remaining weekday hours plus weekends/holidays	Remaining weekday hours plus weekends/holidays

Electric bills for 1997 are summarized in Table 14. The peak billing demand ranged from 355 kW to 440 kW.

Table 14. Air Station electric billing data—COM Electric.

Month	Peak kW	Total kWh	Peak Period kWh	Low Period A kWh	Low Period B kWh	Billed Amount $
Jan-97	381	218,700	36,376	73,456	108,868	$20,798
Feb-97	411	230,400	39,997	82,985	107,418	$21,909
Mar-97	377	203,400	32,794	66,750	103,856	$19,409
Apr-97	362	189,180	46,699	51,545	90,936	$18,213
May-97	410	192,600	63,079	38,556	90,965	$18,734
Jun-97	429	224,820	69,206	41,866	113,748	$21,593
Jul-97	432	220,140	70,235	43,735	106,170	$21,191
Aug-97	440	224,280	70,697	43,043	110,540	$21,620
Sep-97	427	216,720	61,377	39,334	116,009	$20,841
Oct-97	355	201,780	61,594	39,663	100,523	$19,336
Nov-97	364	204,480	37,991	64,216	102,273	$19,524
Dec-97	378	223,200	34,368	68,629	120,203	$21,103
Total	440	2,549,700	624,413	653,778	1,271,509	$244,272

Natural gas is purchased from Colonial Gas under rate G-43C. Table 15 presents the natural gas consumption for the master billing account and for Building 3159.

Table 15. Air Station natural gas billing data—Colonial Gas.

Month	Master Bill Account Consumption (ccf)	Total Cost ($)	Building 3159 Consumption (ccf)	Total Cost ($)
Jan-96	23,079	$19,105	4,342	$3,585
Feb-96	21,694	$17,961	3,452	$2,850
Mar-96	21,634	$17,912	3,322	$2,743
Apr-96	16,580	$8,993	3,346	$1,805
May-96	7,299	$3,987	2,442	$1,317
Jun-96	3,045	$1,693	1,618	$873
Jul-96	3,489	$1,932	1,745	$941
Aug-96	3,054	$1,697	1,585	$855
Sep-96	3,143	$1,745	1,641	$885
Oct-96	8,503	$7,275	2,158	$1,834
Nov-96	13,083	$11,167	2,862	$2,432
Dec-96	23,607	$20,110	4,490	$3,815
Total	148,210	$113,577	33,003	$23,934

Electric savings from the fuel cell were calculated based on the fuel cell operating 90 percent of the year (1,576,800 kWh). The impact of reducing the fuel cell load due to the total Air Station load falling below 230 kW is accounted for in this 90 percent factor. Total displaced electric savings of $143,944 were calculated as shown in Table 16.

Table 16. Building 3159 fuel cell electric savings.

	Hours/yr	Energy	Rate	Savings
Demand (Kw)	—	2,400	$3.11	$7,464
Peak (kWh)	1,880	338,400	$0.0273	$9,232
Low A (kWh)	2,020	363,600	$0.0241	$8,774
Low B (kWh)	4,860	874,800	$0.0183	$15,983
Fuel (kWh)	8,760	1,576,800	$0.0650	$102,492
Total savings				$143,944

Several thermal interface options were evaluated for Building 3159. Fuel cell thermal utilizations ranged from 13.4 to 52.4 percent. Using the kBtu thermal savings presented in the summary table and divided into November–April and May–October groupings, the amount of natural gas that would be displaced by the fuel cell at Building 3159 was calculated using the following assumptions: a 90 percent fuel cell availability, a 75 percent boiler efficiency, and 1,000 Btu/Ccf. Table 17 lists these results.

Table 17. Building 3159 displaced boiler gas.

Thermal Load Application (DHW Tank Temp. Set Point)	Displaced Building Gas*		
	Nov – Apr (MMBtu)	May – Oct (MMBtu)	Total (MMBtu)
Kitchen DHW only (160 °F)	584	399	983
Non-kitchen DHW only (160 °F)	935	510	1,444
Both Kitchen/non-kitchen (160 °F)	1,519	908	2,427
Both Kitchen/non-kitchen (140 °F)	1,467	847	2,315
Space heating only (n/a)	1,484	56	1,540
DHW/space heat (160 °F)	2,516	861	3,377
DHW/space heat (140 °F)	2,952	903	3,855
*(Thermal energy utilized / 75% boiler eff.) x 90% availability x 0.001 MMBtu/kBtu			

The site's G-43 rate is $0.86872/Ccf for the months of November through April and $0.50805/Ccf for the months of May through October. At 1,000 Btu/Ccf, the rates would be $8.69/MMBtu and $5.08/MMBtu, respectively. Table 18 presents a summary of the displaced natural gas savings for the fuel cell thermal application scenarios.

Table 18. Building 3159 thermal energy savings scenarios.

Thermal Load Application (DHW Tank Temp. Set Point)	Thermal Energy Savings		
	Nov – Apr	May – Oct	Total
Kitchen DHW only (160 °F)	$5,077	$2,025	$7,102
Non-kitchen DHW only (160 °F)	$8,119	$2,589	$10,708
Both kitchen/non-kitchen (160 °F)	$13,196	$4,614	$17,810
Both kitchen/non-kitchen (140 °F)	$12,747	$4,305	$17,052
Space heating only (n/a)	$12,894	$284	$13,178
DHW/space heat (160 °F)	$21,857	$4,374	$26,231
DHW/space heat (140 °F)	$25,641	$4,589	$30,230

The Colonial Gas rate that would apply to the fuel cell would be its high load factor schedule, Rate G-53. The rate is $0.85991/Ccf for the months of November through April and $0.50680/Ccf for the months of May through October. At 1,000 Btu/Ccf, the rates would be $8.59/MMBtu and $5.068/MMBtu, respectively. The fuel cell would consume 14,949 MMBtu of natural gas the first year. Input fuel costs would be $101,937 as calculated below:

$63,745 = 7,413 MMBtu x $8.5991/MMBtu (November–April)

$38,192 = 7,536 MMBtu x $5.0680/MMBtu (May–October)

$101,937 = $63,745 + $38,192

Total energy savings from the fuel cell range from \$49,109 to \$72,237:

\$49,109 = \$143,944 + \$7,102–\$101,937

\$72,237 = \$143,944 + \$30,230 – \$101,937

If natural gas could be purchased from the Defense Fuel Supply Center (DFSC) and delivered by Colonial Gas (existing distribution charge of \$0.81/MMBtu) for \$4.50/MMBtu, the input fuel cost would be lowered to \$67,271 (14,949 MMBtu × \$4.50/MMBtu). This is a net savings of \$34,667 over the present Colonial Gas rate schedule and contributes to a direct increase in fuel cell energy savings as follows:

\$83,775 = \$143,944 + \$7,102 – \$67,271

\$106,903 = \$143,944 + \$30,230 – \$67,271

Table 19 summarizes the fuel cell energy savings for the seven thermal utilization cases as well as for the contract gas option.

The estimated savings discussed thus far do not factor in maintenance costs, stack replacement costs, cell stack degradation, or overall lifecycle costs. An analysis was performed to show the net present value (NPV) of savings over the life of the fuel cell. NPV is the sum of future cash flows discounted at a given rate (generally a required rate of return). If NPV is positive, then the project is an acceptable investment. If NPV is negative, then the required rate of return has not been met and the project is not acceptable. Table 20 presents the input assumptions.

The fuel cell installation cost includes a new transformer and a power output controller to ensure that fuel cell electricity is not exported to the COM Electric grid. An additional \$25,000 is added for the installation of a high grade heat exchanger to interface with the space heating loop. Maintenance costs of \$18,000 are based on a commercial rate and represent approximately 1.1 cents/kWh. Stack replacement costs are based on ONSI's projection of one-third the cost of the projected commercial power plant cost of \$1,500/kW (i.e., \$1,500/kW × 200 kW × 1/3). A \$200,000 fuel cell rebate is available through the Department of Energy (DOE) to pay for up to one-third of the fuel cell purchase price. In the model, it was assumed that the fuel cell stack would have a life of 60,000 hours (~ 7 years) and that stack efficiency would degrade based on operating hours.

Table 19. Building 3159 fuel cell energy savings summary.

Case	ECF	TU	Displaced kWh	Displaced Fuel (MMBtu)	Electrical Savings	Thermal Savings	Nat. Gas Cost	Net Savings
Colonial Gas								
Kitchen DHW only (160 °F)	90%	13%	1,576,800	983	$143,944	$7,102	$101,937	$49,109
Non-Kitchen DHW only (160 °F)	90%	20%	1,576,800	1,444	$143,944	$10,708	$101,937	$52,715
Both Kitchen/Non-Kitchen (160 °F)	90%	33%	1,576,800	2,315	$143,944	$17,810	$101,937	$59,817
Both Kitchen/Non-Kitchen (140 °F)	90%	32%	1,576,800	2,427	$143,944	$17,052	$101,937	$59,059
Space Heating Only (n/a)	90%	21%	1,576,800	1,540	$143,944	$13,178	$101,937	$55,185
DHW/Space Heat (160 °F)	90%	46%	1,576,800	3,377	$143,944	$26,231	$101,937	$68,238
DHW/Space Heat (140 °F)	90%	52%	1,576,800	3,855	$143,944	$30,230	$101,937	$72,237
Contract Gas								
Kitchen DHW only (160 °F)	90%	13%	1,576,800	983	$143,944	$7,102	$67,271	$83,775
Non-kitchen DHW only (160 °F)	90%	20%	1,576,800	1,444	$143,944	$10,708	$67,271	$87,381
Both kitchen/non-kitchen (160 °F)	90%	33%	1,576,800	2,315	$143,944	$17,810	$67,271	$94,483
Both kitchen/non-kitchen (140 °F)	90%	32%	1,576,800	2,427	$143,944	$17,052	$67,271	$93,725
Space heating only (n/a)	90%	21%	1,576,800	1,540	$143,944	$13,178	$67,271	$89,851
DHW/space heat (160 °F)	90%	46%	1,576,800	3,377	$143,944	$26,231	$67,271	$102,904
DHW/space heat (140 °F)	90%	52%	1,576,800	3,855	$143,944	$30,230	$67,271	$106,903

Assumptions:

Electric Rate:	$0.0913 /kWh (Average—See COM Electric Rate G-2)
Input Fuel Rate:	$4.50 – $6.82 /MMBtu (Average—See Colonial Gas Rate G-53)
Displaced Fuel Rate:	$7.22 – $7.84 /MMBtu (Average—See Colonial Gas Rate G-43)
Fuel Cell Thermal Output:	700,000 Btu/hour
Fuel Cell Electrical Efficiency (HHV):	36%
Seasonal Boiler Efficiency:	75%

ECF = Fuel cell electric capacity factor

TU = Thermal utilization

Table 20. Building 3159 life-cycle cost-input assumptions.

Capital Cost	$650,000
Installation cost	$125,000*
Maintenance cost	$18,000/yr
Stack replacement cost	$100,000
Fuel cell rebate	$200,000
Stack life	60,000 hr
Cycles per year	1
Escalation rates	3% per year
NPV discount rate	4%, 10%, 15%, 20%
*Add $25,000 for installation of high grade heat exchanger.	

The price of an ONSI PC25C fuel cell recently increased to $850,000. Three fuel cell cost scenarios were analyzed: $850,000, $650,000 (new price with rebate or old price without rebate), and $450,000 (old price with rebate). Table 21 presents 20-year IRR and NPV estimates for the high and the low thermal ranges, and two gas supplier cases presented previously in Table 19. For Colonial Gas, IRRs ranged from 0 to 10.4 percent, and NPVs ranged from $265,029 to -$668,348. For the DFSC scenario, IRRs ranged from 5.7 to 22.1 percent, and NPVs ranged from –$463,978 to $911,486.

Table 21. Building 3159 life-cycle cost summary results.

Case	F.C. Cost	IRR	NPV @ 4%	NPV @ 10%	NPV @ 15%	NPV @ 20%
Colonial	$450k	—	($116,363)	($205,796)	($244,487)	($268,348)
Gas – low	$650k	—	($316,363)	($405,796)	($444,487)	($468,348)
Thermal*	$850k	—	($516,363)	($605,796)	($644,487)	($668,348)
Colonial	$450k	10.4%	$265,029	$10,902	($98,022)	($163,711)
Gas – High	$650k	5.1%	$65,029	($189,098)	($298,022)	($363,711)
Thermal**	$850k	2.1%	($134,971)	($389,098)	($498,022)	($563,711)
DFSC –	$450k	16.2%	$530,093	$177,524	$26,651	($63,978)
Low	$650k	9.5%	$330,093	($22,476)	($173,349)	($263,978)
*Thermal**	$850k	5.7%	$130,093	($222,476)	($373,349)	($463,978)
DFSC –	$450k	22.1%	$911,486	$394,222	$173,115	$40,660
High	$650k	14.2%	$711,486	$194,222	($26,885)	($159,340)
*Thermal***	$850k	9.9%	$511,486	($5,778)	($226,885)	($359,340)

* Low Thermal = Kitchen DHW load only (160 °F)
** High Thermal = Kitchen/non-kitchen DHW (140 °F) + space heating

Tables 22 through 25 show output of the lifecycle cost models for the four scenarios. Note that this analysis is a general overview of the potential savings from the fuel cell. Since detailed load energy profiles were not available, net energy savings could vary depending on actual thermal and electrical utilization.

Table 22. Building 3159 (Colonial Gas, low-thermal utilization case) 20-year life-cycle analysis.

Fuel Cell Costs		Fuel Cell Performance		Operation		Financial	
Capital Cost ($/kW)	$3,250	Electrical Efficiency (HHV)	0.36	Equipment Life (Years)	20	Demand Savings ($/year)	7,464
Installation Cost ($/kW)	$625	Overall Efficiency (HHV)	0.73	Capacity Factor	0.9	Energy Savings ($/year)	136,480
Maintenance Cost ($/YR.)	$18,000	Cell Voltage (volts/cell)	0.7	Cycles per Year	1	Input Fuel Cost ($/year)	101,937
Stack Replacement Cost ($/kW)	$500	Cycle Degradation (mV/cycle)	6	Displaced Boiler Efficiency	0.75	Thermal Savings ($/year)	7,102
Fuel Cell Rebate ($/kW)	$1,000	Operating Degradation (mV/1000 hrs)	2	Thermal Utilization (MMBtu/yr.)	983.0	Inflation	0.03
		Stack Life (Hours)	60,000			Fuel Escalation	0.03
		Fuel Cell Size (kW)	200			Electric Escalation	0.03
		Months of Demand Reduction:	12			NPV Discount Rate	0.10

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Intermediate Calculations																				
Hours																				
Operation Hours/Yr.	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884
Total Operation Hours	7,884	15,768	23,652	31,536	39,420	47,304	55,188	63,072	70,956	78,840	86,724	94,608	102,492	110,376	118,260	126,144	134,028	141,912	149,796	157,680
Total Stack Hours	7,884	15,768	23,652	31,536	39,420	47,304	55,188	3,072	10,956	18,840	26,724	34,608	42,492	50,376	58,260	6,144	14,028	21,912	29,796	37,680
Degradation (V)																				
Operating	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0031	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0061	0.0079	0.0079	0.0079	0.0079
Cycling	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060
Net Cell Volts	0.6861	0.6722	0.6583	0.6445	0.6306	0.6167	0.6028	0.6909	0.6770	0.6632	0.6493	0.6354	0.6215	0.6076	0.5937	0.6879	0.6740	0.6601	0.6462	0.6323
Operation Values																				
Electrical Eff (%)	35.3%	34.6%	33.9%	33.1%	32.4%	31.7%	31.0%	35.5%	34.8%	34.1%	33.4%	32.7%	32.0%	31.2%	30.5%	35.4%	34.7%	33.9%	33.2%	32.5%
Thermal Eff (%)	37.7%	38.4%	39.1%	39.9%	40.6%	41.3%	42.0%	37.5%	38.2%	38.9%	39.6%	40.3%	41.0%	41.8%	42.5%	37.6%	38.3%	39.1%	39.8%	40.5%
Demand Disp. (kW)	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Electric Output (MWh)	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8
Thermal Displ. (MMBtu)	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0
Fuel Input (MMBtu)	15,251	15,566	15,895	16,237	16,595	16,968	17,359	15,145	15,456	15,779	16,117	16,469	16,837	17,222	17,624	15,213	15,526	15,853	16,193	16,549
Average Energy Rates																				
Demand Rate ($/kW)	3.11	3.20	3.30	3.40	3.50	3.61	3.71	3.82	3.94	4.06	4.18	4.30	4.43	4.57	4.70	4.85	4.99	5.14	5.29	5.45
Electric Rate ($/kWh)	0.0866	0.0892	0.0918	0.0946	0.0974	0.1003	0.1034	0.1065	0.1096	0.1129	0.1163	0.1198	0.1234	0.1271	0.1309	0.1348	0.1389	0.1431	0.1474	0.1518
Gas Rate ($/MMBtu)	7.22	7.44	7.66	7.89	8.13	8.38	8.63	8.89	9.15	9.43	9.71	10.00	10.30	10.61	10.93	11.26	11.59	11.94	12.30	12.67
F.C. Gas Rate ($/MMBtu)	6.68	6.88	7.09	7.30	7.52	7.75	7.98	8.22	8.47	8.72	8.98	9.25	9.53	9.82	10.11	10.41	10.73	11.05	11.38	11.72
Fuel Cell Savings																				
Energy Savings ($)																				
Demand	7,464	7,688	7,919	8,156	8,401	8,653	8,912	9,180	9,455	9,739	10,031	10,332	10,642	10,961	11,290	11,629	11,978	12,337	12,707	13,088
Energy	136,480	140,574	144,792	149,135	153,609	158,218	162,964	167,853	172,889	178,075	183,418	188,920	194,588	200,425	206,438	212,631	219,010	225,581	232,348	239,319
Displaced Fuel	7,102	7,315	7,535	7,761	7,993	8,233	8,480	8,735	8,997	9,266	9,544	9,831	10,126	10,430	10,742	11,065	11,397	11,739	12,091	12,453
Subtotal ($)	151,046	155,577	160,245	165,052	170,004	175,104	180,357	185,768	191,341	197,081	202,993	209,083	215,355	221,816	228,471	235,325	242,384	249,656	257,146	264,860
Costs ($)																				
Fuel Cost	101,937	107,164	112,706	118,588	124,835	131,475	138,539	124,497	130,861	137,609	144,768	152,369	160,446	169,036	178,178	158,413	166,526	175,130	184,259	193,954
Maintenance	18,000	18,540	19,096	19,669	20,259	20,867	21,493	22,138	22,802	23,486	24,190	24,916	25,664	26,434	27,227	28,043	28,885	29,751	30,644	31,563
Stack Replacement	-	-	-	-	-	-	-	126,677	-	-	-	-	-	-	-	160,471	-	-	-	-
Subtotal ($)	119,937	125,704	131,803	138,258	145,095	152,342	160,032	273,311	153,663	161,095	168,958	177,285	186,110	195,469	205,405	346,927	195,411	204,881	214,903	225,518
Annual Savings	31,109	29,874	28,442	26,795	24,909	22,761	20,325	(87,544)	37,678	35,986	34,035	31,798	29,246	26,347	23,066	(111,602)	46,973	44,775	42,242	39,343
Cumulative Savings	31,109	60,983	89,425	116,219	141,128	163,890	184,215	96,671	134,349	170,335	204,370	236,167	265,413	291,760	314,826	203,224	250,197	294,972	337,214	376,557
Net Present Value	(405,796)																			
Int. Rate Of Return	-3.7%																			

Table 23. Building 3159 (Colonial Gas, high-thermal utilization case) 20-year life-cycle analysis.

Fuel Cell Costs		Fuel Cell Performance		Operation		Financial	
Capital Cost ($/kW)	$3,250	Electrical Efficiency (HHV)	0.36	Equipment Life (Years)	20	Demand Savings ($/year)	7,464
Installation Cost ($/kW)	$750	Overall Efficiency (HHV)	0.73	Capacity Factor	0.9	Energy Savings ($/year)	136,480
Maintenance Cost ($/YR.)	$18,000	Cell Voltage (volts/cell)	0.7	Cycles per Year	1	Input Fuel Cost ($/year)	101,937
Stack Replacement Cost ($/kW)	$500	Cycle Degradation (mV/cycle)	6	Displaced Boiler Efficiency	0.75	Thermal Savings ($/year)	30,230
Fuel Cell Rebate ($/kW)	$1,000	Operating Degradation (mV/1000 hrs)	2	Thermal Utilization (MMBtu/yr.)	3,855.0	Inflation	0.03
		Stack Life (Hours)	60,000			Fuel Escalation	0.03
		Fuel Cell Size (kW)	200			Electric Escalation	0.03
		Months of Demand Reduction:	12			NPV Discount Rate	0.10

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Intermediate Calculations																				
Hours																				
Operation Hours/Yr.	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884
Total Operation Hours	7,884	15,768	23,652	31,536	39,420	47,304	55,188	63,072	70,956	78,840	86,724	94,608	102,492	110,376	118,260	126,144	134,028	141,912	149,796	157,680
Total Stack Hours	7,884	15,768	23,652	31,536	39,420	47,304	55,188	3,072	10,956	18,840	26,724	34,608	42,492	50,376	58,260	6,144	14,028	21,912	29,796	37,680
Degradation (V)																				
Operating	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0031	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0061	0.0079	0.0079	0.0079	0.0079
Cycling	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060
Net Cell Volts	0.6861	0.6722	0.6583	0.6445	0.6306	0.6167	0.6028	0.6909	0.6770	0.6632	0.6493	0.6354	0.6215	0.6076	0.5937	0.6879	0.6740	0.6601	0.6462	0.6323
Operation Values																				
Electrical Eff (%)	35.3%	34.6%	33.9%	33.1%	32.4%	31.7%	31.0%	35.5%	34.8%	34.1%	33.4%	32.7%	32.0%	31.2%	30.5%	35.4%	34.7%	33.9%	33.2%	32.5%
Thermal Eff (%)	37.7%	38.4%	39.1%	39.9%	40.6%	41.3%	42.0%	37.5%	38.2%	38.9%	39.6%	40.3%	41.0%	41.8%	42.5%	37.6%	38.3%	39.1%	39.8%	40.5%
Demand Disp. (kW)	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Electric Output (MWh)	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8
Thermal Displ. (MMBtu)	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0
Fuel Input (MMBtu)	15,251	15,566	15,895	16,237	16,595	16,968	17,359	15,145	15,456	15,779	16,117	16,469	16,837	17,222	17,624	15,213	15,526	15,853	16,193	16,549
Average Energy Rates																				
Demand Rate ($/kW):	3.11	3.20	3.30	3.40	3.50	3.61	3.71	3.82	3.94	4.06	4.18	4.30	4.43	4.57	4.70	4.85	4.99	5.14	5.29	5.45
Electric Rate ($/kWh):	0.0866	0.0892	0.0918	0.0946	0.0974	0.1003	0.1034	0.1065	0.1096	0.1129	0.1163	0.1198	0.1234	0.1271	0.1309	0.1348	0.1389	0.1431	0.1474	0.1518
Gas Rate ($/MMBtu):	7.84	8.08	8.32	8.57	8.83	9.09	9.36	9.64	9.93	10.23	10.54	10.85	11.18	11.52	11.86	12.22	12.58	12.96	13.35	13.75
F.C. Gas Rate ($/MMBtu):	6.68	6.88	7.09	7.30	7.52	7.75	7.98	8.22	8.47	8.72	8.98	9.25	9.53	9.82	10.11	10.41	10.73	11.05	11.38	11.72
Fuel Cell Savings																				
Energy Savings ($):																				
Demand:	7,464	7,688	7,919	8,156	8,401	8,653	8,912	9,180	9,455	9,739	10,031	10,332	10,642	10,961	11,290	11,629	11,978	12,337	12,707	13,088
Energy:	136,480	140,574	144,792	149,135	153,609	158,218	162,964	167,853	172,889	178,075	183,418	188,920	194,588	200,425	206,438	212,631	219,010	225,581	232,348	239,319
Displaced Fuel:	30,230	31,137	32,071	33,033	34,024	35,045	36,096	37,179	38,294	39,443	40,627	41,845	43,101	44,394	45,726	47,097	48,510	49,966	51,465	53,008
Subtotal ($):	174,174	179,399	184,781	190,325	196,034	201,915	207,973	214,212	220,638	227,258	234,075	241,098	248,330	255,780	263,454	271,357	279,498	287,883	296,520	305,415
Costs ($):																				
Fuel Cost:	101,937	107,164	112,706	118,588	124,835	131,475	138,539	124,497	130,861	137,609	144,768	152,369	160,446	169,036	178,178	158,413	166,526	175,130	184,259	193,954
Maintenance:	18,000	18,540	19,096	19,669	20,259	20,867	21,493	22,138	22,802	23,486	24,190	24,916	25,664	26,434	27,227	28,043	28,885	29,751	30,644	31,563
Stack Replacement:	-	-	-	-	-	-	-	126,677	-	-	-	-	-	-	-	160,471	-	-	-	-
Subtotal ($):	119,937	125,704	131,803	138,258	145,095	152,342	160,032	273,311	153,663	161,095	168,958	177,285	186,110	195,469	205,405	346,927	195,411	204,881	214,903	225,518
Annual Savings:	54,237	53,696	52,979	52,067	50,940	49,573	47,941	(59,099)	66,976	66,163	65,117	63,812	62,221	60,311	58,049	(75,569)	84,087	83,002	81,616	79,898
Cumulative Savings:	54,237	107,933	160,911	212,978	263,918	313,491	361,432	302,333	369,309	435,472	500,589	564,401	626,621	686,932	744,982	669,412	753,499	836,501	918,117	998,015
Net Present Value:	(189,098)																			
Int. Rate Of Return	5.1%																			

Table 24. Building 3159 (contract gas, low-thermal utilization case) 20-year life-cycle analysis.

Fuel Cell Costs		Fuel Cell Performance		Operation		Financial	
Capital Cost ($/kW)	$3,250	Electrical Efficiency (HHV)	0.36	Equipment Life (Years)	20	Demand Savings ($/year)	7,464
Installation Cost ($/kW)	$625	Overall Efficiency (HHV)	0.73	Capacity Factor	0.9	Energy Savings ($/year)	136,480
Maintenance Cost ($/YR.)	$18,000	Cell Voltage (volts/cell)	0.7	Cycles per Year	1	Input Fuel Cost ($/year)	67,271
Stack Replacement Cost ($/kW)	$500	Cycle Degradation (mV/cycle)	6	Displaced Boiler Efficiency	0.75	Thermal Savings ($/year)	7,102
Fuel Cell Rebate ($/kW)	$1,000	Operating Degradation (mV/1000 hrs)	2	Thermal Utilization (MMBtu/yr.)	983.0	Inflation	0.03
		Stack Life (Hours)	60,000			Fuel Escalation	0.03
		Fuel Cell Size (kW)	200			Electric Escalation	0.03
		Months of Demand Reduction:	12			NPV Discount Rate	0.10

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Intermediate Calculations																				
Hours																				
Operation Hours/yr	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884
Total Operation Hours	7,884	15,768	23,652	31,536	39,420	47,304	55,188	63,072	70,956	78,840	86,724	94,608	102,492	110,376	118,260	126,144	134,028	141,912	149,796	157,680
Total Stack Hours	7,884	15,768	23,652	31,536	39,420	47,304	55,188	3,072	10,956	18,840	26,724	34,608	42,492	50,376	58,260	6,144	14,028	21,912	29,796	37,680
Degradation (V)																				
Operating	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0031	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0061	0.0079	0.0079	0.0079	0.0079
Cycling	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060
Net Cell Volts	0.6861	0.6722	0.6583	0.6445	0.6306	0.6167	0.6028	0.6909	0.6770	0.6632	0.6493	0.6354	0.6215	0.6076	0.5937	0.6879	0.6740	0.6601	0.6462	0.6323
Operation Values																				
Electrical Eff (%)	35.3%	34.6%	33.9%	33.1%	32.4%	31.7%	31.0%	35.5%	34.8%	34.1%	33.4%	32.7%	32.0%	31.2%	30.5%	35.4%	34.7%	33.9%	33.2%	32.5%
Thermal Eff (%)	37.7%	38.4%	39.1%	39.9%	40.6%	41.3%	42.0%	37.5%	38.2%	38.9%	39.6%	40.3%	41.0%	41.8%	42.5%	37.6%	38.3%	39.1%	39.8%	40.5%
Demand Disp. (kW)	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Electric Output (MWh)	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8
Thermal Displ. (MMBtu)	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0	983.0
Fuel Input (MMBtu)	15,251	15,566	15,895	16,237	16,595	16,968	17,359	15,145	15,456	15,779	16,117	16,469	16,837	17,222	17,624	15,213	15,526	15,853	16,193	16,549
Average Energy Rates																				
Demand Rate ($/kW)	3.11	3.20	3.30	3.40	3.50	3.61	3.71	3.82	3.94	4.06	4.18	4.30	4.43	4.57	4.70	4.85	4.99	5.14	5.29	5.45
Electric Rate ($/kWh)	0.0866	0.0892	0.0918	0.0946	0.0974	0.1003	0.1034	0.1065	0.1096	0.1129	0.1163	0.1198	0.1234	0.1271	0.1309	0.1348	0.1389	0.1431	0.1474	0.1518
Gas Rate ($/MMBtu)	7.22	7.44	7.66	7.89	8.13	8.38	8.63	8.89	9.15	9.43	9.71	10.00	10.30	10.61	10.93	11.26	11.59	11.94	12.30	12.67
F.C. Gas Rate ($/MMBtu)	4.41	4.54	4.68	4.82	4.96	5.11	5.27	5.42	5.59	5.76	5.93	6.11	6.29	6.48	6.67	6.87	7.08	7.29	7.51	7.73
Fuel Cell Savings																				
Energy Savings ($)																				
Demand	7,464	7,688	7,919	8,156	8,401	8,653	8,912	9,180	9,455	9,739	10,031	10,332	10,642	10,961	11,290	11,629	11,978	12,337	12,707	13,088
Energy	136,480	140,574	144,792	149,135	153,609	158,218	162,964	167,853	172,889	178,075	183,418	188,920	194,588	200,425	206,438	212,631	219,010	225,581	232,348	239,319
Displaced Fuel	7,102	7,315	7,535	7,761	7,993	8,233	8,480	8,735	8,997	9,266	9,544	9,831	10,126	10,430	10,742	11,065	11,397	11,739	12,091	12,453
Subtotal ($)	151,046	155,577	160,245	165,052	170,004	175,104	180,357	185,768	191,341	197,081	202,993	209,083	215,355	221,816	228,471	235,325	242,384	249,656	257,146	264,860
Costs ($)																				
Fuel Cost:	67,271	70,720	74,378	78,260	82,382	86,764	91,425	82,159	86,359	90,812	95,536	100,553	105,883	111,551	117,585	104,541	109,895	115,573	121,598	127,996
Maintenance:	18,000	18,540	19,096	19,669	20,259	20,867	21,493	22,138	22,802	23,486	24,190	24,916	25,664	26,434	27,227	28,043	28,885	29,751	30,644	31,563
Stack Replacement:	-	-	-	-	-	-	-	126,677	-	-	-	-	-	-	-	160,471	-	-	-	-
Subtotal ($):	85,271	89,260	93,474	97,929	102,642	107,631	112,918	230,973	109,161	114,298	119,727	125,469	131,546	137,985	144,811	293,055	138,780	145,324	152,242	159,559
Annual Savings:	65,775	66,317	66,771	67,123	67,362	67,473	67,438	(45,206)	82,180	82,783	83,266	83,614	83,809	83,831	83,659	(57,730)	103,604	104,332	104,904	105,301
Cumulative Savings:	65,775	132,092	198,863	265,986	333,348	400,821	468,259	423,053	505,233	588,016	671,283	754,897	838,706	922,537	1,006,197	948,466	1,052,071	1,156,403	1,261,307	1,366,608
Net Present Value:	(22,476)																			
Int. Rate Of Return	9.4%																			

Table 25. Building 3159 (contract gas, high-thermal utilization case) 20-year life-cycle analysis.

Fuel Cell Costs		Fuel Cell Performance		Operation		Financial	
Capital Cost ($/kW)	$3,250	Electrical Efficiency (HHV)	0.36	Equipment Life (Years)	20	Demand Savings ($/year)	7,464
Installation Cost ($/kW)	$750	Overall Efficiency (HHV)	0.73	Capacity Factor	0.9	Energy Savings ($/year)	136,480
Maintenance Cost ($/YR.)	$18,000	Cell Voltage (volts/cell)	0.7	Cycles per Year	1	Input Fuel Cost ($/year)	67,271
Stack Replacement Cost ($/kW)	$500	Cycle Degradation (mV/cycle)	6	Displaced Boiler Efficiency	0.75	Thermal Savings ($/year)	30,230
Fuel Cell Rebate ($/kW)	$1,000	Operating Degradation (mV/1000 hrs)	2	Thermal Utilization (MMBtu/yr.)	3,855.0	Inflation	0.03
		Stack Life (Hours)	60,000			Fuel Escalation	0.03
		Fuel Cell Size (kW)	200			Electric Escalation	0.03
		Months of Demand Reduction:	12			NPV Discount Rate	0.10

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Intermediate Calculations																				
Hours																				
Operation Hours/Yr.	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884	7,884
Total Operation Hours	7,884	15,768	23,652	31,536	39,420	47,304	55,188	63,072	70,956	78,840	86,724	94,608	102,492	110,376	118,260	126,144	134,028	141,912	149,796	157,680
Total Stack Hours	7,884	15,768	23,652	31,536	39,420	47,304	55,188	3,072	10,956	18,840	26,724	34,608	42,492	50,376	58,260	6,144	14,028	21,912	29,796	37,680
Degradation (V)																				
Operating	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0031	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0079	0.0061	0.0079	0.0079	0.0079	0.0079
Cycling	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060
Net Cell Volts	0.6861	0.6722	0.6583	0.6445	0.6306	0.6167	0.6028	0.6909	0.6770	0.6632	0.6493	0.6354	0.6215	0.6076	0.5937	0.6879	0.6740	0.6601	0.6462	0.6323
Operation Values																				
Electrical Eff (%)	35.3%	34.6%	33.9%	33.1%	32.4%	31.7%	31.0%	35.5%	34.8%	34.1%	33.4%	32.7%	32.0%	31.2%	30.5%	35.4%	34.7%	33.9%	33.2%	32.5%
Thermal Eff (%)	37.7%	38.4%	39.1%	39.9%	40.6%	41.3%	42.0%	37.5%	38.2%	38.9%	39.6%	40.3%	41.0%	41.8%	42.5%	37.6%	38.3%	39.1%	39.8%	40.5%
Demand Disp. (kW)	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Electric Output (MWh)	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8	1,576.8
Thermal Displ. (MMBtu)	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0	3855.0
Fuel Input (MMBtu)	15,251	15,566	15,895	16,237	16,595	16,968	17,359	15,145	15,456	15,779	16,117	16,469	16,837	17,222	17,624	15,213	15,526	15,853	16,193	16,549
Average Energy Rates																				
Demand Rate ($/kW)	3.11	3.20	3.30	3.40	3.50	3.61	3.71	3.82	3.94	4.06	4.18	4.30	4.43	4.57	4.70	4.85	4.99	5.14	5.29	5.45
Electric Rate ($/kWh)	0.0866	0.0892	0.0918	0.0946	0.0974	0.1003	0.1034	0.1065	0.1096	0.1129	0.1163	0.1198	0.1234	0.1271	0.1309	0.1348	0.1389	0.1431	0.1474	0.1518
Gas Rate ($/MMBtu)	7.84	8.08	8.32	8.57	8.83	9.09	9.36	9.64	9.93	10.23	10.54	10.85	11.18	11.52	11.86	12.22	12.58	12.96	13.35	13.75
F.C. Gas Rate ($/MMBtu)	4.41	4.54	4.68	4.82	4.96	5.11	5.27	5.42	5.59	5.76	5.93	6.11	6.29	6.48	6.67	6.87	7.08	7.29	7.51	7.73
Fuel Cell Savings																				
Energy Savings ($)																				
Demand	7,464	7,688	7,919	8,156	8,401	8,653	8,912	9,180	9,455	9,739	10,031	10,332	10,642	10,961	11,290	11,629	11,978	12,337	12,707	13,088
Energy	136,480	140,574	144,792	149,135	153,609	158,218	162,964	167,853	172,889	178,075	183,418	188,920	194,588	200,425	206,438	212,631	219,010	225,581	232,348	239,319
Displaced Fuel	30,230	31,137	32,071	33,033	34,024	35,045	36,096	37,179	38,294	39,443	40,627	41,845	43,101	44,394	45,726	47,097	48,510	49,966	51,465	53,008
Subtotal ($)	174,174	179,399	184,781	190,325	196,034	201,915	207,973	214,212	220,638	227,258	234,075	241,098	248,330	255,780	263,454	271,357	279,498	287,883	296,520	305,415
Costs ($)																				
Fuel Cost	67,271	70,720	74,378	78,260	82,382	86,764	91,425	82,159	86,359	90,812	95,536	100,553	105,883	111,551	117,585	104,541	109,895	115,573	121,598	127,996
Maintenance	18,000	18,540	19,096	19,669	20,259	20,867	21,493	22,138	22,802	23,486	24,190	24,916	25,664	26,434	27,227	28,043	28,885	29,751	30,644	31,563
Stack Replacement	-	-	-	-	-	-	-	126,677	-	-	-	-	-	-	-	160,471	-	-	-	
Subtotal ($)	85,271	89,260	93,474	97,929	102,642	107,631	112,918	230,973	109,161	114,298	119,727	125,469	131,546	137,985	144,811	293,055	138,780	145,324	152,242	159,559
Annual Savings	88,903	90,139	91,307	92,396	93,393	94,284	95,055	(16,761)	111,478	112,960	114,349	115,629	116,784	117,796	118,643	(21,698)	140,718	142,559	144,278	145,856
Cumulative Savings	88,903	179,042	270,349	362,745	456,138	550,422	645,477	628,715	740,193	853,153	967,501	1,083,130	1,199,914	1,317,710	1,436,352	1,414,655	1,555,373	1,697,932	1,842,210	1,988,066
Net Present Value	194,222																			
Int. Rate Of Return	14.2%																			

4 Conclusions and Recommendations

This study concluded that Building 3159 at the U.S. Coast Guard Air Station Cape Cod, MA was the only viable site for fuel cell installation. It was recommended that the fuel cell electrical interface at this building be made through a new 300 kVA transformer tied into either the 208/120 V panel in the electrical room or the 4160 V side of the existing building transformer. Fuel cell electrical output not used at Building 3159 would go into the Air Station base grid.

Several thermal interface options were evaluated. These included DHW for the kitchen, DHW for the residents, and space heating for the entire building. Supplying all three loads resulted in the highest fuel cell thermal utilization (52 percent) versus supplying only the kitchen DHW (13 percent). Interfacing with the space heating load or maintaining the DHW tank at its current 160 °F would require the installation of a high grade heat exchanger option for the fuel cell.

There is space available for locating the fuel cell just outside the mechanical room. Thermal piping runs are relatively short. The electrical interface would be approximately 100 ft over to the existing transformer.

Energy savings for eight thermal interface options and two input fuel suppliers were calculated. Annual energy savings ranged from $49,109 to $72,237 for the Colonial Gas cases and $83,775 to $106,903 for contract gas purchases through D.F.S.C cases.

Lifecycle costs showed 20-year IRRs of between zero and 12 percent based on a fuel cell cost of $650,000 (current cost of fuel cell less $200,000 rebate).

Appendix: Fuel Cell Site Evaluation Form

Site Name: **U.S. Coast Guard Air Station Cape Cod** Contacts: **Jim Candee**
Location: **New London, CT**

1. Electric Utility: **COM Electric/Narragansett** Rate Schedule: **G-2**

2. Gas Utility: **Colonial Gas** Rate Schedule: **G-43**

3. Available Fuels: **Natural gas, diesel**

4. Hours of Use and Percent Occupied:

Weekdays	_____	hrs	_____
Saturday	_____	hrs	_____
Sunday	_____	hrs	_____

5. Outdoor Temperature Range:
   Design dry bulb temperatures: 14 °F to 79 °F
   Extremes: 11 °F to 85 °F

6. Environmental Issues: **No major issues anticipated.**

7. Backup Power Need/Requirement: **Three backup generators at Air Station.**

8. Utility Interconnect/Power Quality Issues: COM Electric also serves FAA station. Interconnection needs to be evaluated. **Total load below 200 kW during off hours sometimes.**

9. On-site Personnel Capabilities: **Plant maintenance personnel.**

10. Access for Fuel Cell Installation: **Access available from street and parking area.**

11. Daily Load Profile Availability: **Electric load data to be provided by COM Electric.**

12. Security: **Base to decide on fence surrounding fuel cell.**

Site Layout

Facility Type: **Barracks** Age: **26 years**

Construction: **Concrete block with brick fascia. Exterior insulation just installed.**

Square Feet: **36,700 sq ft**

See Figures 1 & 2

Show:

- **electrical/thermal/gas/water interfaces and length of runs**
- **drainage**
- **building/fuel cell site dimensions**
- **ground obstructions**

Electrical System

Service Rating: **4160 V distributed on base grid**
4,160/208 V, 300 kVA transformer at Building 3159
COM Electric 1,000 kVA transformer feeds Air Station area.

Electrically Sensitive Equipment: **N/A.**

Largest Motors (hp, usage): **N/A.**

Grid Independent Operation?: **Possible application. Decision to be made by base.**

Steam/Hot Water System

Description: **Two low-pressure steam boilers.**

System Specifications: **Kewanee 5 MMBtu/hr**
Weil-McLain 320,000 Btu/hr.

Fuel Type: **Natural gas.**

Max Fuel Rate:

Storage Capacity/Type: **1600 gal**

Interface Pipe Size/Description:

End Use Description/Profile: **Kewanee boiler operates during heating season. Steam used to heat 1600-gal hot water storage tank to 160 °F.**

Space Cooling System

Description: **Several window A/C units.**

Air Conditioning Configuration:
Type:
Rating:
Make/Model:

Seasonality Profile:

Space Heating System

Description: **Hydronic heating loop feeds individual heats throughout buildings.**

Fuel: **Natural gas.**

Rating:

Water supply Temp: **100 – 180 °F, 11 psi steam.**

Water Return Temp: **90 – 160 °F condensate return.**

Make/Model:

Thermal Storage (space?): **N/A**

Seasonality Profile: **Space heating provided from about 15 October to sometime in April. Large boiler operates in winter; small boiler operates in summer.**

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14. ABSTRACT

Fuel cells are an environmentally clean, quiet, and a highly efficient method for generating electricity and heat from natural gas and other fuels. Researchers at the U.S. Army Engineer Research and Development Center (ERDC), Construction Engineering Research Laboratory (CERL) have actively participated in the development and application of advanced fuel cell technology since fiscal year 1993 (FY93). CERL selected and evaluated application sites, supervised the design and installation of fuel cells, actively monitored the operation and maintenance of fuel cells, and compiled "lessons learned" for feedback to manufacturers of commercially available fuel cell power plants and their thermal interfaces installed at Department of Defense (DoD) locations. This report presents an overview of the information collected at the U.S. Coast Guard Academy, New London, CT, along with a conceptual fuel cell installation layout and description of potential benefits the technology can provide at that location.

15. SUBJECT TERMS
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